IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received October 10, 2018, accepted October 28, 2018, date of publication November 1, 2018, date of current version December 3, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2879061

Toward a M2M-Based Internet of Vehicles Framework for Wireless Monitoring Applications

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This work was supported in part by the National Natural Science Foundation of China under Grant 61571241 and Grant 61872423, in part by the Ministry of Education-China Mobile Research Foundation, China, under Grant MCM20170205, in part by the Scientific Research Foundation of the Higher Education Institutions of Jiangsu Province, China, under Grant 15KJA510002 and Grant 17KJB510043, in part by the Six Talent Peaks Project in Jiangsu Province under Grant DZXX-008, and in part by the Research Foundation for Advanced Talents of the Nanjing University of Posts and Telecommunications under Grant NY217146.

ABSTRACT The Internet of Vehicles (IoV) has become an attractive research topic in the fields of communication networks and information processing due to its wide range of potential applications, including public transportation management, road traffic predication and control, environmental monitoring, and autonomous driving. Most research analyze the IoV's data collected by dedicated machine-to-machine (M2M)-based platforms. Moreover, due to the lack of field experimental data, data transmission mechanisms from mobile vehicle terminals to the M2M-based platform rarely consider the proper transmission timing according to network performance and traffic conditions. To solve these problems, we propose an open M2M-based framework of wireless monitoring system for IoV. In the proposed framework, we design and implement a prototype of the mobile vehicle terminal. We also define the procedure of data transmission between the mobile vehicle terminal and the M2M-based platform. To prolong the lifetime of the mobile vehicle terminal, energy-efficient data transmission schemes for stopped and running vehicles are proposed, respectively, which reduce the unnecessary data transmission by jointly considering the variation of vehicle speed and received signal strength. We conduct a field experiment to verify the basic functions of the proposed M2M-based IoV monitoring system and the mobile vehicle terminal. Furthermore, the experimental results show that the proposed M2M-based platform with the mobile vehicle terminal enables customized and energy-efficient data delivery.

INDEX TERMS Internet of vehicles, machine-to-machine, mobile vehicle terminal, network coverage quality, energy saving.

I. INTRODUCTION

The internet of things (IoT) internet of things (IoT) has become one of the significant factors to trigger the new round economic and technological development in terms of the public transportation, national security, agriculture, environmental protection, medical service, etc. [1]–[3]. By leveraging the machine-to-machine (M2M) communication, the IoT realizes the connections among a large number of different devices, which inspires the versatile commercial opportunities [4], [5]. In 2013, INTEL created a new business department for the IoT investment. CISCO specifically invested the Accelerator Project for the research and development (R&D) of IoT. A new business department of IoT in IBM provided private cloud services for various enterprises incorporated with innovative development tools to fully utilize the data generated by IoT devices. HUAWEI and ZTE, as two pioneers of telecommunication, offer different M2M-based solutions to ensure high efficiency communications with low cost when numerous M2M-based terminals are simultaneously accessed to communication networks. The European research cluster forecasted that the non-networking equipment will become a smaller part of the house electronics, declining from about 75% in 2010 to 25% in 2020 [6]. The traditional telecommunication operators, such as AT&T, Verizon, SK Telecom (SKT), Docomo, and China Mobile Communication Company (CMCC), have introduced M2M-based platform to realize the unified access and management of IoV terminals [7], [8]. The unified M2M-based platform significantly reduces business and usage cost by employing open application programming interfaces (API) integrated the IoT standards, which successfully attract potential users of the small and medium enterprises [9].

The internet of vehicles (IoV) is a typical application of the IoT relied on the M2M communication [3], [10]. Road and vehicle information, such as road conditions, position and velocity of vehicles, and received signal strength (RSS), can be collected by mobile vehicle terminals and then transmitted to the M2M-based platform through cellular networks [11], [12]. Though the real-time processing and analysis, the strategies of traffic control and public transportation management can be adjusted to improve the performance of IoV [13].

Most studies of IoV's data analysis focus on different application requirements. For example, Huang *et al.* [14] proposed an approach of traffic congestion avoidance according the historical traffic information. Reference [15] proposed a mobile monitoring scheme for the potential airborne nuclear, biological, and chemical monitoring. On the aspect of data transmission between vehicle terminals and M2M-based platform, many researches utilized coordination schemes to reduce energy consumption on idle listening for vehicle terminals [16]. Moreover, fairly allocation of wireless resources for diverse vehicle terminals was investigated in [17]. However, it is worth noting that frequent data transmission consumes a large amount of energy because transmitting and receiving power dominate the energy consumption during wireless communications [18]. Thus, selecting proper transmission timings to reduce the number of unnecessary data transmission (e.g., redundant information) can prolong the lifetime of the vehicle terminal's batteries and thereby improving the performance of IoV.

In this paper, we design an M2M-based IoV monitoring system that includes mobile vehicle terminal (we called "iBox"), an M2M-based platform, and service components for data analysis. We design and implement a prototype of iBox that can report collected information to the proposed M2M-based platform. The information includes positions and velocity of vehicles, RSS, and status of vehicles (obtained by on-board diagnostics (OBD) system). According to the information, the proposed M2M-based IoV monitoring system not only conduct the real-time traffic monitoring, but also evaluate the wireless network coverage quality. Moreover, the M2M-based IoV monitoring system provides the service components that extract the fundamental functions of data processing, to enable the customized data analysis. Furthermore, energy-efficient data transmission approaches are proposed to reduce the energy consumption of iBox when it communicates to the M2M-based platform. We consider two scenarios of vehicles, including running and parked. Specially, vehicles choose a proper timing to transmit data to the M2M-based platform by jointly considering the variation of vehicles' velocity and RSS. The iBox will enter to the sleep mode if the vehicle parks for a long time. We conduct the field experiment to verify the proposed M2M-based IoV monitoring system and present the novel performance of the proposed energy-efficient data transmission scheme.

The rest of this paper is organized as follows. In Section II, we summarize the related work in M2M-based IoV monitoring system with two aspects: IoV data analysis and efficient data transmission schemes. In Section III, we propose the architecture of the M2M-based IoV monitoring system in terms of system structure, iBox design, and service components design. We elaborate energy-efficient data transmission schemes in Section IV. We present the performance evaluation of the proposed system and data transmission approaches via field experiment in Section V and conclude this paper in Section VI.

II. RELATED WORK

In this section, we summarize the typical research in two aspects as mentioned in Section I: IoV's data analysis for different applications and efficient data transmission approaches for mobile vehicle terminals.

A. IoV's DATA ANALYSIS

The current IoV's data analysis aims at particular scenarios or applications. Huang *et al.* [14] proposed a timely shortest path selection algorithm for drivers by using historical traffic information collected from IoV. The traffic information includes position information and duration and starting time of crowded roads. Thus, the shortest path selection was formulated as a congestion avoidance problem based on the traffic information. More theoretically, an analysis and optimal design of routing method for public transportation networks was proposed in [19]. The time delay of passing a road is modeling as a state-dependent decaying service rate with the M/G/c/c queue. Under this model, the route assignment is formulated as an integer program. Road clearance time, traveled distance, and road congestion level were adopted to evaluate the proposed routing approach. In [20], an integrated traffic emergency framework was proposed to derive the optimal path and evacuation strategy using the traffic demand estimation model for different transport modes (e.g., bus, subway, car, etc.) restricted by spatial-temporal distribution of the estimated traffic demand. For environmental monitoring, [15] proposed a mobile monitoring scheme using sensors mounted on vehicles for potential airborne nuclear, biological, and chemical monitoring. The number of required sensors for a given network coverage was derived based on the analysis of the information volume. Reference [17] proposed a monitoring framework for vehicle pollution. By using wireless sensor networks and designed electrochemical toxic gas sensors, the real-time pollution monitoring can be efficiently achieved. Furthermore, Mohan *et al.* [22] defined the pollution level of vehicle to enable the efficient environmental monitoring. To enhance the public security, the vehicle is equipped with external surveillance cameras to achieve the real-time vehicle tracking and control under the fundamental structure of IoV [23].

B. DATA TRANSMISSION SCHEMES

At the aspect of the mobile vehicle terminal, Salman *et al.* [24] reduced the system energy consumption by network resources allocation optimization with limited hardware resources. Even though the utilization ratio of the terminal resources is improved, the allocation algorithm lacked fairness among different vehicle terminals, which result in a service failure when a single terminal is not able to effectively utilize the network resources. Showk *et al.* [25] proposed the structure of a mobile vehicle terminal, including hardware layer, the operating system layer, and the modem subsystem. Based on the structure, the authors proposed a task scheduling and the service control algorithm that can achieve a wide bandwidth data transmission. Reference [26] proposed a wake-up delay scheduling mechanism in a manner of time slots to reduce energy consumption. Reference [27] aimed at the optimized rail traffic transmission by using a mixed integer linear programming. Some studies proposed data transmission strategies via the communication between vehicle terminals and M2M-based platform. For example, Chen *et al.* [28] designed an agent plugin for a vehicle terminal to achieve task scheduling. Because of the significant energy consumption caused by poor network connectivity, [29] allows multiple mobile terminals to access networks simultaneously. The connection request with a poor network quality is rejected in advance, thereby prolonging the lifetime of mobile vehicle terminal.

In general, the current studies of IoV monitoring system focus on the specific cases using dedicated platforms. The costs of system development and deployment are quite high with less data sharing and reuse. Furthermore, few data transmission strategies jointly consider both the wireless network quality and the vehicle's speed to conserve energy. Consequently, in this paper, we propose a comprehensive framework of the open M2M-based IoV monitoring system. We design and implement a prototype of iBox to deliver real-time data to the M2M-based platform via telecommunication networks. The mobile vehicle terminal can collect not only the position information of vehicles, but also the status of vehicles, including engine status, gas emission, etc. The proposed M2M-based IoV monitoring system can utilize collected data to predict the road traffic condition and monitor the city environment. We also extract the fundamental functions of data processing to design service components for customized data analysis. To reduce data transmission cost of the mobile vehicle terminal usage, we propose energy-efficient data transmission schemes by jointly considering the variation of vehicle's speed and RSS. Besides, a sleep scheduling mechanism is introduced to conserve energy when the vehicle is not running.

We summarize the main contributions of this paper as follows. First, we design a comprehensive framework of M2M-based IoV monitoring system with a prototype of the mobile vehicle terminal. Second, we propose energy-efficient data transmission schemes for the proposed mobile vehicle terminal. Last, we conduct field experiments to verify the whole system and evaluate the performance of the proposed data transmission schemes.

III. DESIGN METHOD

In this section, we introduce the architecture of the M2M-based IoV monitoring system. At first, we provide an overview of whole system. Then, the design of iBox is presented in detail. We also define the communication procedure between the M2M-based platform and iBox. Finally, we elaborate the design of service components for customized data analysis.

A. SYSTEM OVERVIEW

We present the architecture of the M2M-based wireless monitoring system in Figure 1. The iBox collects data that are transmitted to the M2M-based platform through wireless communication. The connection management, data storage, and data management/analysis modules of the M2M-based wireless monitoring system directly provide data to users for different applications, such as parking management, vehicle information acquirement, and position/navigation services. Furthermore, the M2M-based monitoring system offers

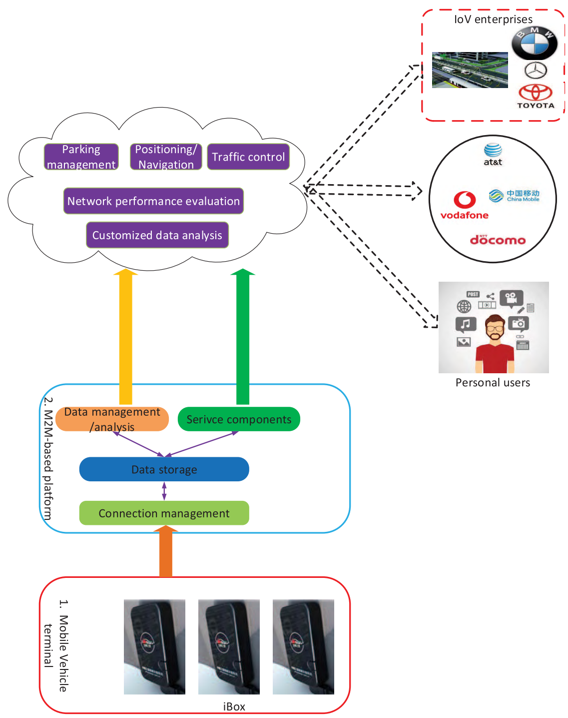

FIGURE 1. The architecture of M2M-based IoV monitoring system.

diverse service components to developers (e.g., third parties or over the top (OTT)), which enables the customized data analysis for different scenarios.

B. iBox DESIGN

The dimension of the iBox is 162mm (height) × 120mm (width) × 58mm (depth), which is convenience to deploy in the vehicle. As shown in Figure 2, the iBox consists of a microcontroller unit (MCU), an OBD module, a global positioning system (GPS) module, a radio frequency (RF) module, an accelerometer module, a microphone module, a flash memory, and three indicators. The three indicators represent the working status of iBox, the positioning status of the vehicle, and the networking status. A 12-pin external port is utilized to connect the OBD interface of a vehicle through an extension cable. Moreover, each iBox is powered by external battery and is identified by a unique ID (i.e., 4 bytes, 00000001-00FFFFFF).

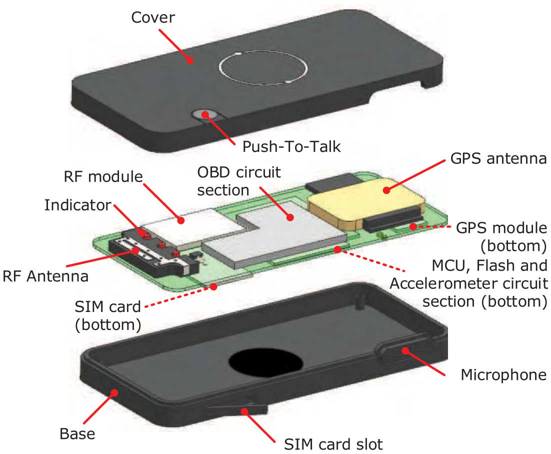

FIGURE 2. The structure of the iBox.

In addition, the iBox supports the voice broadcast mode for the warning service in cases of long time driving and abnormal movement of vehicles. In the voice broadcast mode, users can configure the alarm thresholds through IoV platform or mobile APPs. The iBox will alarm by the built-in loudspeaker if detecting some abnormal events. The push-to-talk bottom is used to communicate with M2M-based platform.

C. INTERACTION BETWEEN iBox AND M2M-BASED PLATFORM

The iBox is embedded with the wireless M2M protocol (WMMP) [30] to enable the communication between the mobile vehicle terminals and the M2M-based platform. Figure 3 shows the interaction between the iBox and the M2M-based platform. At the beginning, the iBOX will register to the M2M-based platform using international mobile subscriber identity (IMSI). Then, the M2M-based platform will generate a session secret key after receiving the login request (i.e., LOGIN_REQ) from the iBox. The session secret

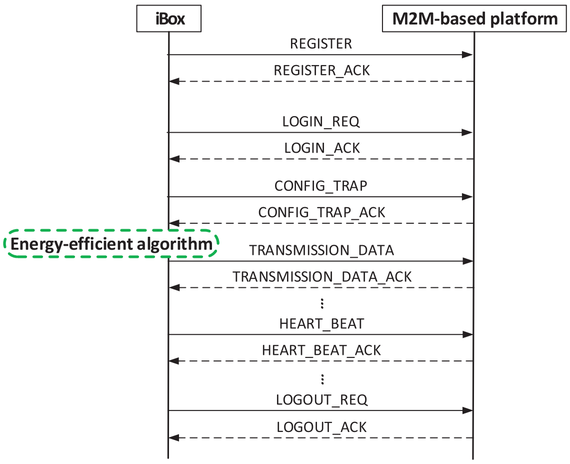

FIGURE 3. Communication procedure between iBox and M2M-based platform.

key is employed in the subsequent interactions including configuration and data transmission.

The parameters regarding the iBox, such as the alarm threshold of iBox, the number of retransmissions, are configured to the M2M-based platform via CONFIGURATION_TRAP, as shown in Figure 3. In the data transmission (i.e., TRANSMISSION_DATA in Figure 3), the position information with corresponding RSS, the ID of an iBox, and OBD data (e.g., the car's speed, the battery/oil usage, etc.) are reported to the M2M-based platform. HEART_BEAT and HEART_BEAT_ACK are used to detect the communication link between iBox and the M2M-based platform.

D. SERVICE COMPONENTS DESIGN

As mentioned in Section II-A, the M2M-based platform relies on the data analysis and management modules to provide the original data for different applications. Furthermore, to simplify software development, the M2M-based platform provides the service components that the users can achieve different services via different combination of service components. The services can be called and presented via webservice.

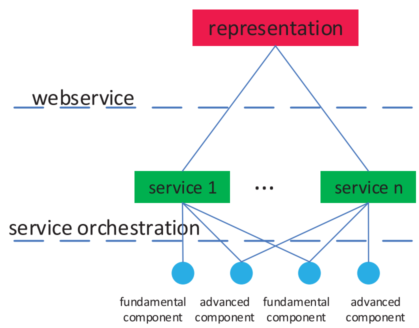

FIGURE 4. The structure of service components.

There are two types of service components as shown in Figure 4: fundamental component and advanced component. The fundamental component offers the basic capacities of data processing, which includes the comma-separated values (CSV) input and output, the data redundancy reduction, the string manipulation, the numeric sorting, etc. Users can configure these components based on their own requirements. For instance, the user can specify different data types for the CSV input component. Furthermore, the data analysis and representation are also supported by the advanced components, such as the counter and classification components. The preliminary data statistics and display can be conducted incorporated with the fundamental and advanced components. For instance, the user can adopt the CSV input, the data redundant reduction, the string manipulation, and the classification and statistic components, to analyze car's speed.

IV. ENERGY-EFFICIENT ALGORITHMS

In this section, we propose energy-efficient data transmission approaches for iBox reporting data to the M2M-based platform. An energy-efficient data transmission for iBox when the vehicle is running is proposed. Then, we present a sleep scheduling mechanism for iBox when the vehicle parks.

A. ENERGY-EFFICIENT DATA TRANSMISSION SCHEME

It is obvious that frequently reporting similar data to the M2M-based platform consumes a large amount of energy and results in unnecessary data redundancy. Therefore, we propose an energy-efficient data transmission scheme (EEDTS), which aims to reduce unnecessary data transmission to conserve energy. The fundamental idea is that the iBox periodically report the current data to the M2M-based platform only if there is a significant difference between the current data and received data in the previous time slot. At the beginning of each period, EEDTS employs a transmission cost to determine whether to transmit data immediately or not. The data without transmitted are stored in the local buffer of iBox, which can be delivered to the M2M-based platform offline. The transmission cost is jointly considered the variations of position information and RSS, which is expressed as

$$C = \frac{1}{n}\sum_{i=1}^{n}(\alpha \Delta D_i + (1-\alpha)\Delta W_i). \tag{1}$$

In (1), α is the weight of the variation of position information and $1-\alpha$ is the weight of the variation of RSS. At the period i, ΔD_i indicates the variation of vehicles' position and ΔW_i is used to evaluate the variation of the RSS. We introduce n, as the number of times of data collection, to alleviate the impact of the error caused by a single collection. The variation of vehicle's position is expressed by

$$\Delta D_i = 1 + \log\left(\frac{\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} + \frac{1}{N-1}d}{d}\right), \tag{2}$$

$$d = \sum_{n=2}^{N}\sqrt{(x_i - x_{i-n+1})^2 + (y_i - y_{i-n+1})^2}, \tag{3}$$

where (x_i, y_i) is the coordinates of the vehicle's location (provided by GPS) acquired by the iBox at period i. The variation of RSS is presented as follows.

$$\Delta W_i = \frac{n}{2}\left(\frac{|W_i - W_{i-1}|}{\sum_{i=1}^{n}|W_{i+1} - W_{i-n+1}|}\right), \tag{4}$$

where W_i and W_{i-1} are the values of RSS sampled by the iBox at period i and $i-1$, respectively.

If the transmission cost is equal or more than 1, iBox will report the data to the M2M-based platform. Otherwise, iBox store the data without reporting immediately. We summarize the EEDTS in Algorithm 1 as follows.

Algorithm 1 Energy-Efficient Data Transmission Scheme (EEDTS) for iBox

```
The iBox is connected with OBD port of vehicles which
  will be ignited and started later, Set Time1;
if n < 3 then
  Continuously acquire data;
  if no alarm then
    record OBD data;
  else
    transfer a real-time alarm;
  end if
end if
for the selection of each sampling value do
  Evaluate ΔD_i and ΔW_i;
end for
Evaluate joint transmit cost C;
Implement the data transmission when C ≥ 1;
```

B. SLEEP SCHEDULING MECHANISM

If a vehicle stops at a same location longer more than a predefined threshold, the accelerometer module of the iBox will generate a rising interrupt signal (from the low level to the high level) to the MCU. Then, the MCU shuts down other components of the iBox (except accelerometer module) to enter the sleep mode. It is worth noting that the accelerometer module sends out the falling interrupt signal (from the high level to the low level) to wake up the MCU module once detecting a motion event of the vehicle. The MCU turns on the circuits of both GPS and RF modules. If the variation of collected data (i.e., position information of a vehicle) is smaller than a predefined threshold, the iBox will only report the vibration and alarm signal. Otherwise, the iBox starts to report data to the M2M-based platform (how the iBox chooses the timing to report data to the M2M-based platform is detailed in the above section).

The above mechanism is refereed to as sleep scheduling mechanism (SSM), which is summarized in Algorithm 2.

Algorithm 2 Sleep Scheduling Mechanism (SSM) for iBox

```
The iBox is connected with OBD port, the engine of car
is stopped, and set Timer 2;
if Timer 2 expires then
    The iBox enters into the sleep mode;
    Turn off the MCU, OBD, RF and GPS modules;
    The accelerometer module starts the real-time moni-
    toring;
    if motion event is detected then
        The MCU, RF and GPS modules are awakened;
    end if
    if Position change < the predefined threshold then
        Send the vibration alarm signals;
    else
        Send the alarm with position information;
        if iBox receives a 'positioning' request then
            Report the vehicle's position;
        end if
    end if
end if
```

V. EXPERIMENT RESULTS

A. iBox IMPLEMENTATION AND FIELD EXPERIMENT SETTINGS

The prototype of iBox is shown in Figure 5. iBox is deployed on the car for the road test. The RF module is implemented by SIM900 that works in the 1800/1900 MHz industrial scientific medical (ISM) band. The module supports global system for mobile communications (GSM) / general packet radio service (GPRS) protocols with the data rate from 14.4 Kbps to 57.6 Kbps. n in Algorithm 1 is 3. The predefined threshold in Algorithm 2 is 120 s. In addition, when detecting the voltage of iBox's external batteries is under 11.8V without the vibration alarm for more than 120 minutes, the iBox will be turned off due to the low battery power. These parameters can be configured by an mobile APP client. iBox and M2M-based platform incorporated with the mobile APP client can provide different services such as vehicle anti-theft, road rescue, road traffic prediction, and repair and maintenance services.

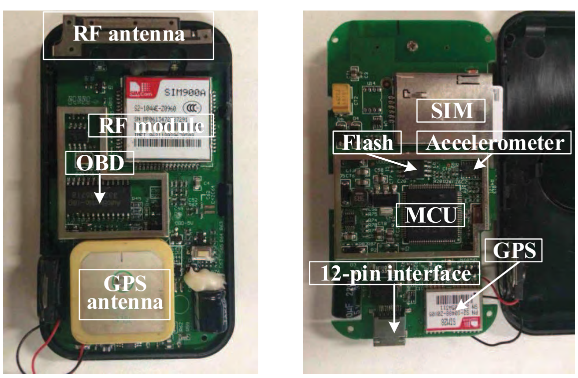

FIGURE 5. A prototype of iBox main board, left: front view; right: bottom.

We conducted the field experiment collaborated with CMCC in Nanjing, 2017. The road tests lasted different time durations in order to test and verify different functions of the proposed M2M-based monitoring system. The longest experiment lasted more than six days, which includes different scenarios such as clear road, morning rush hour, and poor network coverage.

B. BASIC TEST

The basic test verifies the communication between the iBox and the M2M-based platform. The M2M-based platform can effectively monitor and manage the wireless communication link. As shown in Figure 6, the M2M-based platform can monitor and manage the information in terms of message type, message payload, message length, and direction of data transmission.

No.	Reporting Time	Message Type	Message ID	Message	Direction
1	11/9/2017 8:21	OBD	AAB00F	52	terminal->platform
2	11/9/2017 8:22	GPS	AAC13E	33	terminal->platform
3	11/9/2017 8:23	Heart beat	AAD00F	15	terminal->platform
4	11/9/2017 8:24	Heart beat	AAD00G	15	platform->terminal
5	11/9/2017 8:25	GPS	AAE09D	33	terminal->platform
6	11/9/2017 8:26	GPS	AAC06D	33	terminal->platform

FIGURE 6. Real-time IoV data transmission.

The RSS with the position information of vehicles is collected by iBox (GPS module). The iBox sends data to the M2M-based platform every 5 seconds. We defined the relationship between the RSS and the network quality in Table 1, which is used to evaluate the network coverage quality of the cellular mobile network by the operators. The larger value of the signal quality indicates the better network quality and vice versa.

TABLE 1. Relation between signal strength and network quality.

Signal quality (SQ)	RSS	Network quality
$22 \sim 31$	$\geq -70dbm$	✓✓✓✓
$14 \sim 21$	$-85dbm \sim -70dbm$	✓✓✓
$9 \sim 13$	$-95dbm \sim -85dbm$	✓✓
$1 \sim 8$	$-120dbm \sim -95dbm$	✓

FIGURE 7. GUI of M2M-based IoV monitoring system.

Figure 7 shows the main graphical user interface (GUI) of M2M-based IoV monitoring system. The M2M-based system dots with different colors to indicate different coverage qualities of the wireless network, which is convenient for telecommunication operators to query and evaluate network performance. Users can obtain the detail of each point, including time, network protocol, RSS, etc.

C. PERFORMANCE EVALUATION OF EEDTS

We evaluate the performance of the proposed EEDTS at different times. The alpha is 0.2 and the whole experiment lasted six hours. Figure 8 reports the variation of external batteries' voltage every 15 minutes (0.25 hour) and the red plotting series indicates the relative performance of EEDTS over the voltage of external batteries. As shown in Figure 8, we observe that the proposed EEDTS outperforms the data transmission scheme without jointly considering both the network coverage and the speed of vehicles at different times. Moreover, it is obvious that the EEDTS can significantly reduce energy consumption if the iBox works long time. We realize that the relative performance of EEDTS is up to 76%. The main reasons are that the iBox can recognize the congested road by sensing the variation of the vehicle's speed and store the data in the buffer if the variation of vehicle's speed is not significant. On the other hand, the iBox with EEDTS can identify the different qualities of network coverage quality (i.e., RSS). The iBox only report data to the M2M-based platform when the network coverage quality is poor.

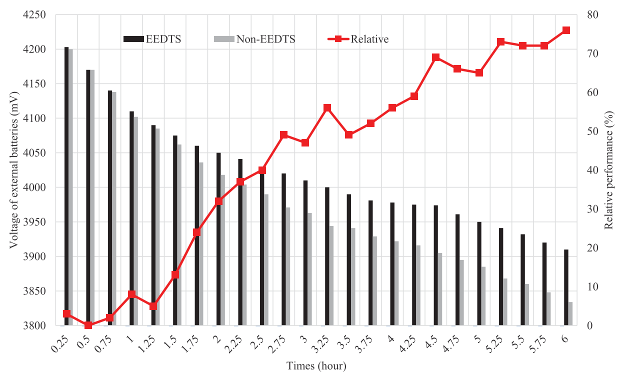

FIGURE 8. Variation of external batteries' voltage in six hours, EEDTS vs. Non-EEDTS.

Furthermore, we investigate the two factors' contributions to the energy-efficient data transmission respectively, including vehicle's speed and network coverage quality. We compare the performance of EEDTS with only considering the variation of vehicle's speed (i.e., $\alpha = 1$) with that only considering the network coverage quality (i.e, $\alpha = 0$). As shown in Figure 9, EEDTS with variation speed can conserve more energy than that with network coverage quality. The red plotting series present the maximum relative performance is up to 30%. It demonstrates that the traffic jam frequently occurs in the city rather than the poor quality of network coverage. The telecommunication operators, such as CMCC, maintain a novel network quality by deploying different base stations in the city. In general, the proposed EEDTS can effectively

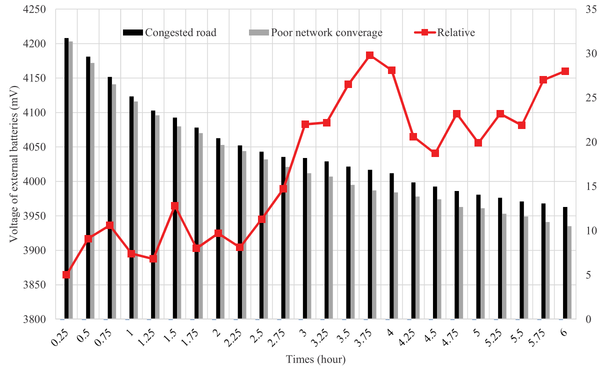

FIGURE 9. Variation of external batteries' voltage: congested road and poor network coverage.

reduce the redundant data transmission caused by the traffic congestion.

We also evaluate the performance of the proposed EEDTS for a fixed ranges if vehicle's speed or RSS in the transmission cost (recall Equation 1). We deploy three iBox in one vehicle for road test to configure different weights (i.e, α) for vehicle's speed variation and RSS. The three iBox are referred to as IT1, IT2, and IT3.

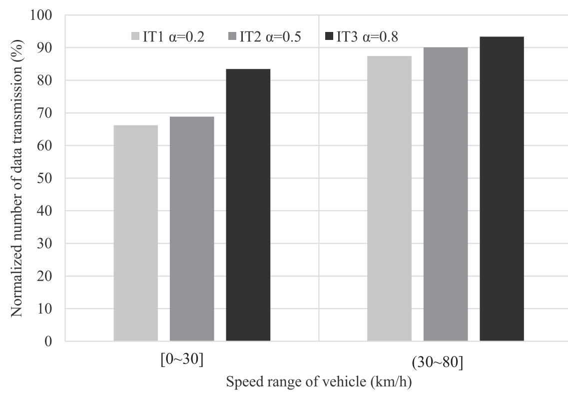

FIGURE 10. Normalized number of data transmission vs. vehicle's speed.

Figure 10 presents the normalized number of data transmission under certain ranges of the vehicle speed when RSS is larger than -85 dBm. It is worth nothing that the road traffic condition and the velocity of vehicles are difficult to specify during the field experiment. Thus, the speed ranges of the vehicle are employed to represent the road traffic conditions. In our field experiment, $0 \sim 30$ km/h and $40 \sim 80$ km/h present the congested and clear road condition, respectively. It is obvious that the normalized number of data transmission in a clear road condition is higher than that in a congested condition due to the larger value of C (recall Equation 1) caused by the significant variation of vehicle's speed. In this case, the low normalized number of data transmission represents the low energy consumption, which means the proposed data transmission scheme can effectively reduce the number of data transmission when the vehicle's speed does not have evident changes (i.e., the variation of vehicle's speed in a congested road is tiny). Furthermore, for a given speed range of the vehicle, we observe that the normalized number of data transmission is higher when the value of α is larger. The reason is that, for a given network coverage quality, the larger value of α represents the more consideration on the variation of vehicle's speed. The smaller value of α can reduce more energy consumption when the network coverage quality is fixed.

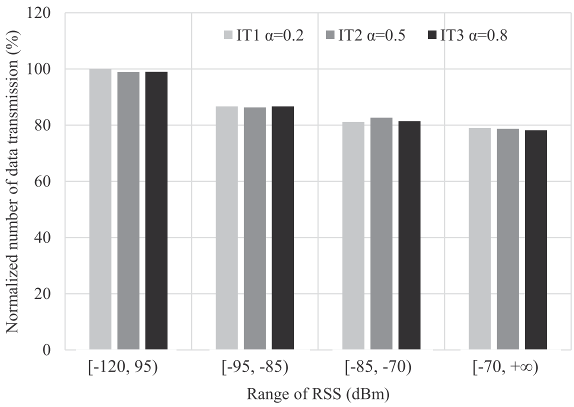

FIGURE 11. Normalized number of data transmission vs. network coverage quality (RSS).

Figure 11 shows the normalized number of data transmission under different network coverage qualities (i.e., RSS). The average speed of the vehicle with iBox is around 30 km/h. The normalized number of data transmission with novel network coverage quality is smaller than that with worse network coverage quality. The reason is that the novel network coverage leads to a small value of C (recall Equation 1) and the proposed data transmission scheme conserves energy by limiting the number of data transmission. We also observe that, for a given network coverage quality, the normalized numbers of data transmission under different values of α do not have an obvious difference because the proposed transmission cost is not sensitive to the variation of the network coverage quality consideration when the vehicle's speed is fixed.

In addition, to verify and evaluate the proposed SSM, the vibration alarm is triggered by opening or closing the door of the vehicle. The vibrations caused by the vehicle's engine (i.e., the vehicle is ready to run) and other factors (e.g., opening or closing the vehicle's door, natural vibration, etc.) can be effectively differentiated by the proposed SSM incorporated with the accelerometer module of iBox. We study the voltage changing of the external batteries of iBox in six days. As shown in Figure 12, it is obvious that the proposed sleep scheduling mechanism can significantly reduce energy consumption by forcing the iBox entering the sleep mode when the vehicle parks. The relative performance

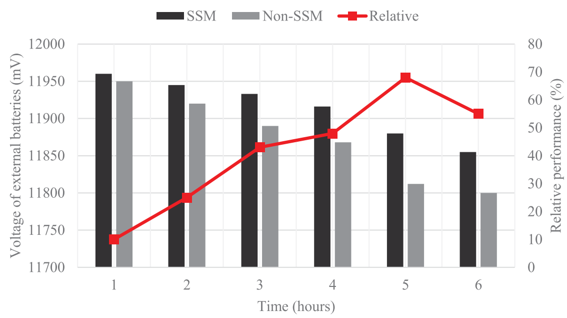

FIGURE 12. Variation of external batteries' voltage in continuous days when the vehicle in the parking state, SSM vs. Non-SSM.

of the proposed SSM is up to 70% compared with that without SSM.

VI. CONCLUSION

In this paper, we propose an M2M-based IoV monitoring system. We design and implement a prototype of the mobile vehicle terminal that can effectively collect diverse information including the position and velocity of vehicles, OBD data, and RSS. The collected data can be directly employed for different applications. We also provide various service components to customize data analysis. Furthermore, we propose energy-efficient data transmission schemes by considering two status of vehicles: stop and running status. The mobile vehicle terminal will enter the sleep mode when the vehicle stops for a long time and will choose an appropriate timing to transmit data to the M2M-based platform to reduce unnecessary data delivery when the vehicle is running. The field experimental results verify the basic functions of the proposed M2M-based IoV monitoring system and present the novel performance of the proposed energy-efficient data transmission schemes.

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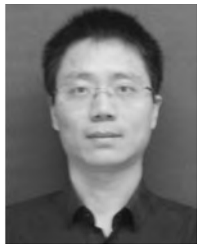

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